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MODERN VIEWS UPON THE DEVELOPMENT OF LUNG FIBROSIS*

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I. NEW ASPECTS OF THE PROBLEM

In 1918 Haldane (1) published a short and very suggestive paper on the cause of serious lung injury from dust. He pointed out that silicious dust had been thought to be harmful if present in the air in any considerable amount, but that he had become acquainted with certain instances in which this did not seem to be true, work in high percentages of silicious dust being apparently uninjurious. He then discussed the fact that coal miners who breathe coal and shale dust remain comparatively free from serious lung disease. This he harmonized with experimental work done by Mavrogordato (2), who caused guinea-pigs to breathe air laden with six different dusts: coal, shale, quartz from the Transvaal, flint, material from flues, and pure precipitated silica. He found that high concentrations of any of these dusts resulted in heavy deposition in the lungs, with marked congestion and cellular proliferation. His observations did not continue long enough to permit the widespread development of fibrous tissue, but there is apparently no doubt that it would have occurred.

The significant fact of the experiments was brought out by moderate exposures, when it was found that "While coal dust and shale dust enter the lung with great readiness they do not produce, under these conditions, permanent lesions; and the lung might pass for normal after a twelvemonth. Flue dust and crystalline silica are not eliminated with such readiness." The important suggestion of the experiments is, then, that dusts which do harm are those which for some reason or other are not eliminated. Carbon particles, according to Haldane and Mavrogordato, cause rather a violent reaction when they reach the pulmonary alveoli, which results in their quick seizure by phagocytes and their elimination; while crystalline silica, a notably harmful dust, enters the lung with equal readiness, causes little reaction, remains in the lung tissue and slowly induces fibrosis.

It will be shown later that Mavrogor-

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dato makes many claims as to the manner in which dust is removed from the lungs, which are out of accord with the observations of other investigators. But analytical disagreements have nothing to do with his most important contention, namely, that rate of dust invasion is not more important than rate of dust elimination. When dust reaches the lung alveoli there are three ways by which it may get out:

1. By the bronchi—the route taken on coming in. The sputum of individuals who have worked in coal dust invariably shows particles, and a fair percentage of these have probably been down in the lungs and up again. They are noticed clinging to bits of mucus or within large cells which are constantly, but apparently erroneously, thought to be desquamated epithelial cells from the pulmonary alveoli. Later on the real origin of these cells will be discussed, but at this point it is enough for us to realize that dust particles in the alveoli may be seized by phagocytes which, by ameboid movement, find their way up into the bronchi and then, through the activity of the bronchial cilia, are driven up into the mouth. No doubt, also, the alveoli may fill with semi-fluid exudate which carries particles up on to the cilia, and thence they may be slowly passed on to the mouth.

2. The particles may get through the alveolar walls, reach the lymphatics of the lungs, and be slowly moved toward the lung roots. Present indications point to this second possibility as of most importance.

3. The particles may be taken up from the alveoli by phagocytes which wander into the blood capillaries surrounding the alveoli, and then be carried to various points of elimination. Permar (3) mentions this possibility and feels that it does not occur. While we must admit that there is no direct proof of the removal of foreign material by the blood, there is a certain amount of analogous evidence which is worth considering. Winternitz and Smith (4) have shown that physiological salt solution may be poured into the alveoli of the dog at a rate as high as 3,000 c.c. in 30 minutes. Undoubtedly, removal of this fluid is accomplished by the blood stream. So far as we know there are no direct attempts to ascertain whether solid particles may be removed by the same route. In 1916 Shipley and Cunningham (5) performed experiments which are most suggestive in this direction. They immersed the omentum of the decerebrate cat in a suspension of finely divided carbon, and within a short time were able to detect carbon particles free both in the capillaries of the liver and upon the phagocytic endothelial cells which line them. These particles could not have reached the liver except through the blood stream. By some process, the nature of which is not known, carbon particles pass into the blood capillaries of the omentum and drift up to be arrested in the capillaries of the liver. The situation within the lung alveoli is possibly similar, particles within them being very close to the blood stream and quite as well able to get into these capillaries, as in the case of particles which enter the omental circulation.

If now we review these three methods of removal, it is apparent that phagocytosis plays an exceedingly important, indeed an indispensable part in the process.

II. The Alveolar Phagocytes

Mavrogordato describes the phagocytosis of carbon in the lung of the guinea-pig in the following summary:

(i) The dust cells, mostly cells derived from pulmonary epithelium, take up coal dust with great avidity and are very readily shed. Dust is seen in fixed cells as well as in free cells, but the former are for the most part isolated, and one does not meet islets of dust-loaded cells to any extent.

In the text leading up to this summary he makes such statements as: "Many cells—of large and small endothelial type and dust laden—were to be made out free in the alveoli, but there was also much dust in the fixed cells." And later, in describing experiments with the Transvaal silicious dust, he again speaks of cells of "endothelial type." One cannot decide whether Mavrogordato recognizes the possibility of phagocytosis by actual endothelial cells or uses the term to describe the appearance of cells of epithelial origin. This view, that the alveolar epithelium is responsible, is in agreement with that of many investigators, but it is not confirmed by recent observations; and since the origin and original position of lung phagocytes is of considerable practical importance it is necessary to review the data which have been presented.

The idea that the large flat cells, seen to contain dust in properly exposed animals and persons, are derived from the epithelium is singularly easy to hold. By ordinary methods of staining practically all the cells containing particles, which are found either inside, clinging to the alveolar walls, or within adjacent lung tissue, are indistinguishable from lining epithelial cells. Knauff (6) presented this view many years ago. Ruppert (7), Schottelius (8), Wainwright and Nichols (9), Briscoe (10) and Sewell (11) agree with him. Arnold (12), Oliver (13), Beitzke (14), Watkins-Pitchford (15), and Willis (16) believe that a variety of cells may be responsible. Haythorn (17) and Klotz (18) were the first to hold substantially that the endothelial leukocyte is of importance. Such cells must be derived from the lining of blood capillaries of lymphatics or from the circulating blood. They are, therefore, out of contact with dust as it reaches the alveoli. A definite migration through the lung tissue into the alveolar spaces is necessary in order to bring them into action. Haythorn's identification of the lung phagocytic cells as endothelial depended upon the facts that they were identical in size and appearance with endothelial leukocytes, that they were phagocytic for blood pigment, carbon, and all kinds of cellular debris, and were apparently the same type of cells as were found in tubercles. Gardner (19) studied nearly one hundred dusted guinea-pigs, and during the stage of phagocyte formation failed to find a single mitotic figure within alveolar epithelium. He says:

> . . . Moreover, no trace of dust has been found *within* an attached alveolar epithelial cell. One of Miller's great contributions to our understanding of pulmonary anatomy has been the distention method of fixation. By its use it is possible to determine with a considerable degree of accuracy the relation of one structure or cell to another. If a collapsed or undistended lung be examined, it seems indisputable that dust particles are lying within attached epithelial cells. If, however, the lung be fixed by the distention method, the dust cells, although they may be near the wall, will always be superimposed upon the epithelium or lying at a little distance from the wall. It would seem that the employment of this technical procedure has enabled us to eliminate one of the proposed sources of the intra-alveolar phagocyte.
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> No definite conclusions on this disputed question are possible at this time. The evidence would seem to have reduced the question of the origin of the alveolar phagocyte to a consideration of the local vascular endothelium in the lung and to studies on the transitional cell of the circulating blood.

Neither Haythorn, Klotz, nor Gardner, however, employed staining reactions

which identify endothelial phagocytes. Their conclusions depend upon analogies, or upon attempts to eliminate the alveolar epithelium from consideration. Slavjansky (20) practically accomplished the identification of endothelial cells as the important agents in 1869. He gave intratracheal injections of indigo followed by intravenous injections of cinnabar, and shortly after he found phagocytic cells, containing cinnabar particles and indigo, free in the alveoli. He considered that these cells were mononuclear elements derived from the circulating blood. Tchistovitch (21) used a somewhat similar technic in 1889. Recently Sewell (11) attempted the same sort of experiment but, for technical reasons which need not be outlined, failed in the proper execution of his task.

Foot (22) and Permar (3)—the latter in a very beautiful and conclusive series of observations—have carried through the same type of experiment and leave little doubt as to the final conclusion. The technic used by Permar depends upon the following facts. It has been known for some time that the endothelial leukocyte will take up certain vital stains. Thus, if rabbits or guinea-pigs receive intravenous injections of trypan blue, isamine blue and a number of other dyes, it is found that after a few days certain large cells in the liver, spleen, lymph nodes, and bone marrow are filled with the dye. In the normal animal practically no stained cells are found in the lung. The uninjured endothelium of the blood capillaries and lymphatics does not take up the dye. It has, however, been shown that injured or irritated vascular endothelium very readily becomes phagocytic (23). If, now, the animals are injected intravenously with isamine blue and intratracheally with finely ground carmine, the injections being repeated for several days, one is soon able to find numerous blue-stained endothelial phagocytes in the lung, and these clearly identified cells may then be followed in relation to the phagocytosis of the intra-alveolar carmine.

On examining animals so treated Permar never found the epithelial cells of the alveolar lining either vitally stained or carmine containing. He discovered that the number of blue-stained cells in the lung increased with intratracheal carmine injections and sums up his work as follows:

> . . . The large mononuclear phagocyte of the lung is derived by proliferation from the vascular endothelium, and in large part that of the capillary network in the walls of the air sacs. This proliferative activity is accomplished by mitosis. The point of origin in the pulmonary capillaries is indifferent and determined only by the proximity of an irritant in the lung tissue. The proliferating cell is endowed with an ameboid motion, and once free, migrates directly to the site of the irritant, in the air sacs and bronchial tree. The point of entrance of the wandering cell into the alveoli is equally indifferent, the cell passing directly between the epithelial plaques to gain the free air space where it at once proceeds to collect within its cytoplasm the foreign substance which has called it forth. Ordinary pulmonary anthracosis, now accepted as almost a physiological process, illustrates how slight an irritant may give rise to a proliferative endothelial reaction.

If we return to Haldane's paper we find the following paragraph:

> It is highly probable that insoluble dust particles are attractive and stimulating to dust-collecting cells in proportion to the soluble substances absorbed in the dust particles; and that the particles containing little of these substances will be correspondingly unstimulating. This, at least, seems to me the most probable explanation of why some kinds of insoluble dust stimulate the cells and others do not; and the facts so far known

seem to be consonant with this explanation, though far more work on the whole subject is required.

Haldane then seems to explain the difference between the effects of insoluble carbon dust, which is harmless, and the most dangerous sort of insoluble silicious dust, by the suggestion that the carbon particle, which has to a high degree the power of adsorbing material upon its surface, upon reaching the alveolus becomes coated with material which renders it not only highly irritating so that many phagocytes at once begin to concentrate upon the scene but also highly desirable for phagocytosis. Silica, which is notably non-adsorptive, owes its tendency to remain in the lungs and to resist elimination to the fact that absence of adsorbed material renders it less irritant and less readily phagocytized. In another paragraph, however, he makes the statement that all the different sorts of dust used by Mavrogordato were apparently taken up by phagocytic cells with the same degree of readiness, and the difference between them lies in the fact that cells which have ingested carbon are able to move steadily out of the lung, whereas the reverse is true with silica. In Mavrogordato's words:

> 1. Coal and shale are taken up by cells which are quickly shed, and consequently do not set up processes which block lymphatics. These cells frequently break down, and masses of dust are to be seen on the surface of the alveolar walls.
>
> Flue dust and crystalline silica are taken up by cells which tend to remain *in situ* and form plaques, which appear early and persist. They are the only site of fibrosis made out in this investigation.
>
> Dusts which form plaques are not readily eliminated.

Mavrogordato apparently believed that carbon particles reaching an alveolus stimulated the alveolar epithelium near by to proliferate and to ingest them. Permar, however, has shown that the particle must arouse proliferation in the capillary endothelium with subsequent detachment of cells and migration through the wall into the alveolus. While it is true that such cells have their origin very close to the air space, the actual process involved is somewhat more formidable than that conceived by Mavrogordato, and gives better play for differences in physical characteristics of foreign particles.

On considering this entire situation it seemed wise to attempt an analysis of all the possibilities raised by Haldane and Mavrogordato, keeping in mind their fundamental contention that rate of dust elimination is as important as rate of inhalation, and subjecting the different phases of the process to experimental procedures. One step in this work has been accomplished. It was first desired to find out whether all dusts really were taken up by phagocytic cells with equal degrees of readiness. Fenn (24) has prepared suspensions of carbon and quartz and has shown that the polymorphonuclear leukocytes of the rat ingest carbon four times as readily as quartz. He has recently extended this observation to phagocytes obtained by scraping the surface of the lung—the method employed by Briscoe for obtaining similar material—and thus has shown that in the very first step of the process of removal of foreign material silica lags behind carbon.

III. The Disposal of Foreign Material

In the last section the lung phagocytes have been identified, and the character of the discussion has made it evident that phagocytosis is an extremely important early step in ridding the al-

veoli of foreign material. In early observations upon lung fibrosis investigators (25) advanced the view that particles might pass between the alveolar epithelial cells or actually pierce them to reach the lung tissue. These ideas are apparently entirely discounted today. Though there may be differences of opinion as to the cell responsible, there is unanimity that particles leaving the alveoli must first be ingested by phagocytes.

The questions which next arise relate to the length of time required by phagocytes to collect a load of foreign material and their subsequent movements. Haythorn (17) gave soot inhalations to rabbits for eighty-seven days and found pigment-bearing cells, "only in the alveoli and interalveolar spaces and there was no evidence that any had migrated as far as the large lymphatics. All these points seem to indicate that the phagocytic cells are not transient scavengers, but in a more leisurely manner gather their pigment-load and transport it to the tissue spaces." Willis (16) also feels that the "*absorption* [of alveolar phagocytes] must be relatively slow, since in these normal animals [caged guinea-pigs in the laboratory unsubjected to dust inhalations] increments of dust are taken into the lung only very slowly and gradually, yet the dust cells are always seen."

Permar (3), using powdered carmine by intratracheal injection, showed that this material begins to be taken up at once by the few endothelial phagocytes in the alveoli at the time of injection and that, while all the material introduced had not become intracellular in five hours, by the end of twenty-four hours even if the injections were large all the foreign particles were intracellular. He says:

> . . . These cells take on the most extraordinarily heavy loads of pigment, even when the particles are relatively coarse.* As a result, they increase enormously in size, and the nucleus becomes completely masked by the quantities of granules with which the cytoplasm is packed.

This author verifies the observations of Haythorn and Willis on the slowness with which cells which have taken up dust leave the alveoli. He states:

> Though the foreign pigment is entirely intracellular at the end of a twenty-four hour period, the endothelial phagocytes do not leave the alveolus at a rapid rate. On the contrary, there is often very little difference in the picture, even at the end of five or six days. In four animals killed after this interval, the alveoli still seem equally crowded by the same groups of large, heavily loaded cells. This is borne out by the relatively slight change in the number of cells found migrating along the lymphatics after six days as compared with that found after twenty-four hours. In fact, in some animals there seems to be a slowing down after the first acute reaction, and the migrating cells are even fewer in three to five days than after twenty-four hours, indicating a lessened activity after the acuteness of reaction is gone. The actual time period required to effect complete clearing of the alveoli could only be estimated by experiments covering long periods of time, possibly even running into months.

It should be pointed out that the observations so far quoted, Haythorn, Willis, and Permar, have been made (1) by the use of carbon dust, (2) upon ani-

*Fenn (24) has shown that *in vitro* carbon particles 4.7 μ in diameter are ingested as readily as 2.2 μ particles. It has been held rather generally, apparently as a result of findings in South Africa (26), that only very small particles are responsible for damage to the lung. The great majority of silicious particles recovered from the lung postmortem were found to have a diameter less than 1 μ. Particles as large as 12 μ were found in the lung but were very few. The question as to the size of particles which may actually reach the alveoli has never been investigated from a careful quantitative point of view. If large particles do reach the alveoli there is no apparent reason why they should not be picked up by phagocytes and carried into the lung tissue.

mals acquiring a normal degree of lung pigmentation while living under laboratory surroundings, and (3) upon animals receiving intratracheal injections of carmine suspension. The results are in agreement but this does not assure us that flint dust, organic dusts, etc., will bring about similar states of affairs.

Many investigators have reported that dust falling upon the ciliated epithelium of the bronchioles begins to move toward the mouth at once, and after a single moderate dusting these upper passages may become quite clean before material begins to leave the alveoli either in cells which pass through the wall or which move up on to the ciliated surface and are then carried away.

Permar has found, and others are in agreement with him, that phagocytes containing dust tend to accumulate near the alveolar entrance and apparently move through the wall in this neighborhood to enter the terminal lymphatics of the lung which arise about the alveolar ducts. After reaching a lymphatic the dust-carrying phagocyte, partly through its own ameboid activity and partly through the lymph flow, moves toward the lymph nodes at the root of the lung. Twenty-four hours have been found necessary for the traverse of this distance in the case of carmine by Permar, and twenty hours for manganese dioxide by workers in our own laboratory. Whether this rate of travel is reduced after foreign material begins to accumulate, is not known. Permar records a decreased rate of migration from the alveoli five or six days after intratracheal injection of carmine. Since the lymphatics of the lung are found about the blood vessels and bronchi, it is natural to see cells containing pigment, and foci of cellular debris and pigment at such points. Willis has commented upon the fact that in the young guinea-pig there is practically no lymphoid tissue in the lung, but as life goes on lymphoid accumulations begin to appear. These masses are prominent along bronchi and blood vessels, and Willis presents a very beautiful reconstruction of one such fusiform collection about a small artery and comments upon the fact that "Irvine and Watt (27) described an irregular periarterial thickening as one of the early lesions in pneumokoniosis and remarked that the thickenings are not 'nodular' formations."

While dust may naturally be found scattered long the lymph passages from their origin to the peribronchial nodes, a good deal is usually seen in such lymphoid collections, and as they continue to enlarge in the face of steady dusting a definite mottling of the lung is produced and areas of lymphoid proliferation begin to be found immediately outside alveoli at the very beginning of lymph channels. Fibrosis apparently takes place in close relation to the lymphatics and to such collections of lymphoid tissue, and it seems probable that both increases in lymphoid collections, through which lymph must flow to reach the root of the lung, and connective tissue encroachment upon lymph channels must combine to slow lymph drainage and to arrest more and more dust-laden phagocytes before they reach their final destination in the lymph nodes at the lung root. It should, however, be remembered that while a certain amount of data exists as to lymph movement out of the peritoneal cavity and out of the limbs, there is no direct knowledge upon the rate of lymph flow in the lungs and upon the factors which bring it about.

Mavrogordato has contended that alveolar phagocytes may wander out of lymphatics and through the walls of large bronchi. His data on this point are

insufficient and are unconfirmed by other observers. The reader will recollect that he distinguished between carbon and silica by the fact that cells containing carbon were eliminated more readily than those containing silica. The cells containing carbon he believes to be quickly shed, apparently chiefly by moving up onto the ciliated epithelium. Silica-containing cells, on the other hand, do not tend to move but are apt to aggregate and form plaques which become foci for fibrosis. Mavrogordato believes that the rate of silica removal can be increased by adding carbon to the air breathed, thus inducing a more vigorous reaction and getting rid of some of the silica as a result of the intense drive at the carbon. He implies that where air has contained silica but workmen have experienced no harm there has been an admixture of carbon or of some dust with similar properties which has kept the silica on the move. Haldane goes so far as to suggest that such mixtures be made artificially in work which demands inhalation of silicious dust.

These are contentions which are not verified experimentally, and, as has been pointed out, the ground upon which they rest seems frequently to be insecure. They are peculiarly susceptible to experimental attack and should either gain our confidence or be cast aside in a few years' time.

IV. Some Final Aspects of the Problem

Collis (28), in his classical lectures upon the pneumokonioses, calls attention to the innocuous character of coal dust, of limestone and plaster of Paris, and speaks especially of crystalline silica as being the principal source of real lung damage. He calls attention to the fact that in the amorphous form this substance is not known to do harm, and that silicates such as clay (aluminum silicate) are also harmless. He remarks:

> Silica dust, then, possesses certain qualities:—(1) physical, (a) such smallness as permits the particles to be carried into the alveoli, and (b) such hardness and angularity as suggest that the particles can act as centres of irritation; and (2) chemical, (a) acidity which, owing to the presence of the element silicon, may render the particles capable of entering into and modifying the colloidal structure of protoplasm, and (b) smell, possibly due to a vapour, as yet undetermined, given off when silica is fractured.

We do not know which or whether any of these properties is responsible for the harm done by silica. To them Haldane has added another, the non-adsorptive power of silica. We call attention to these statements only in order to show how little fundamental exploration of the field there has been. With the exception of Fenn's observations, which deal with carbon and silica alone, we have no data on differences in rate of phagocytic intake, and with the exception of Mavrogordato's somewhat unsupported contentions, no data upon different rates of movement of different dusts which reach the alveoli. While silicious dust is the most deadly, even carbon dust produces some lung damage, and the whole question as to whether pure organic dusts can do significant harm may be regarded as unsettled. Fortunately, the field is one which can be explored through animal experimentation, and it is probable that a period of more exact quantitative investigation is at hand.

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INVESTIGATIVE OPPORTUNITIES IN THE PHYSICAL EXAMINATION OF LARGE GROUPS OF INDIVIDUALS*

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THE physical examination is, or should be, the foundation upon which any plan for supervision of health is constructed. It is, of course, entirely possible to accomplish something without physical examination, but positive results depend upon the amount of real information obtained concerning the individuals whose health is supervised. The old comparison of the examination of personnel with the examination of property, inanimate machinery and product still holds true.

In many ways the actual results of physical examinations in industry have been disappointing. These examinations have demanded the expenditure of time, energy and money. Occasionally they have been remarkably useful and have led to the detection of cases of disease in early and perhaps curable stages. Moreover, they have made it possible to arrange employment better suited to the capability of the worker. In addition, much valuable individual advice has, of course, been given, which has resulted in improvement in the physical condition of the individual workers. Nevertheless, the results of physical examinations do not seem at present to be stated in terms that enable us to appraise the personnel as exactly as the material assets of the industry can be appraised.

There are several reasons for this. In the first place there are no generally accepted standards of health. The Great War demonstrated how standards for acceptance into military service may vary. As has often been said, medical men have mainly studied disease, and usually manifest disease, and are not accustomed to studying health. There are now slowly accumulating data for health standards but this collection of material is of very recent origin. In general our instruments of examination are tested on the sick, and only subsequently do we get the necessary normal controls which are essential to the establishment of health standards. A perhaps familiar illustration is the occurrence of albuminuria in young men. That albumin is occasionally present without significance in the urine of young men has long been known, but it seemed to be agreed that this finding was not compatible with any reasonable standard of health. In the course of the examination of Harvard students, albuminuria is found in about 5 per cent. of the men, the percentage being rather higher in the younger students and rather lower in the older students. In 1920 we found albumin in 7.3 per cent. of approximately 600 freshmen, with an average age of 18. In a group of 400 upper classmen, with an average age of 20, examined at the same time, it was present in only 2.2 per cent., and in a group of 400 students in one of the graduate schools, it was present in less than 2 per cent. Furthermore, on reexamination this percentage is fixed, but

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the individuals vary somewhat. Those who habitually present albuminuria during the day but not at night seem to belong to a particular type. In the cases in which albumin was present in the urine, all of the requisite examinations were, of course, made to prove the presence or absence of a nephritis. In the age group in which we are concerned, nephritis is actually present in less than 1 per cent. of the cases in which albuminuria is found. Inasmuch as albuminuria can be induced in a large percentage of persons by violent exertion, is it necessary to assume that the albuminuria associated with the usual mild exertion of daily life is abnormal? At Harvard University we are continuing our studies on albuminuria in the hope of creating some sort of fairly definite standard of health in respect to this particular condition.

The introduction of the stethoscope has not been an unmixed blessing. Many physicians have acted on the thesis that a heart with a murmur was a damaged heart. At Harvard University Dr. Parmenter has recently studied cardiac murmurs, and has found that approximately 2 per cent. of the students have murmurs and other signs which may safely be accepted as indicating a damaged heart. These figures are essentially the same in similar series in schools and industries, which exclude individuals in the degenerative period of life. On the other hand, in over 70 per cent. of the students a cardiac murmur of considerable intensity, concerning the existence of which there would be no dispute among auditors, can be demonstrated under the appropriate conditions of breathing and posture. With forced expiration without breathing and in the recumbent position, a systolic murmur can usually be heard at the pulmonic area. Such findings certainly suggest that the presence of a systolic murmur is compatible with a reasonable health standard.

I might continue by taking up each item in the physical examination and might point out the necessity for the establishment of a satisfactory standard in each item. There are problems and opportunities for investigation which begin with the first estimations we usually make, namely, the height and weight. The investigative opportunities certainly include the estimation of the blood pressure in which there is increasing evidence that the normal standard for a single observation must be given wide limits which may, however, be progressively restricted with increasing observations.

The physical examination, however, should do very much more than establish the presence or absence of organic disease, although this is, to be sure, the necessary first step toward the utilization of the physical examination in industry. The inadequacy of the usual type of physical examination to answer the question as to whether a given individual is fitted for any particular task has led to the development of so-called physical efficiency tests. The literature is full of physical efficiency tests which vary from a simple strength test to a rather complicated record of achievements under the reproduced specialized conditions of the industry for which the person examined is a candidate. As an illustration of the latter, we have the efficiency test which was developed for aviators. In general, efficiency tests have the same weakness which has been commented upon in the organic examination, namely, the lack of accepted standards. It usually happens that the individual examiner becomes quite expert in observation and interpretation, and he finds the particular test which he

applies extremely valuable, but the tests do not often lend themselves to general use, and when they are put into general use the results are very divergent.

It seemed to us at Harvard University that it ought to be possible to discover by appropriate examinations some acceptable classification of the functional capacity of the different physiological systems. We began with what we termed the mechanical use of the body, and this we studied under two main headings, namely, how the individual stands, and how he uses his feet. We undertook an arbitrary classification into four groups —a classification which has now been in use since 1919, and which has given very satisfactory results. For example, we have classified as group D, which is our lowest and poorest classification of bodily mechanics, from 25 to 35 per cent. of the students. This system of classification enables us at once to visualize, as a group, individuals with marked round shoulders, lordosis, etc.

In 1919, our figures in regard to bodily mechanics, merely on the basis of posture, not on the basis of feet, were: group A = 7.5 per cent.; group B = 12.5 per cent.; group C = 55 per cent.; and group D = 25 per cent. This examination was confined entirely to freshmen. In 1921 the examination of 773 freshmen showed the following results: The percentage of men in the A group was 1.03; in the B group, 22.5; in the C group, 47.7; and in the D group, 25.7. In these last figures the criterion of bodily mechanics was enlarged to include the use of the feet. In the graduate schools 282 students were examined, of which number 0.77 per cent. were in the A group, 15.5 per cent. in the B group, 51.1 per cent. in the C group, and 30.2 per cent. in the D group. This suggests very much that the percentage of people who have a poor mechanical use of the body (and groups C and D represent poor use) is about the same in the older group as it is in the younger group. One sees at once the difference between the results in this particular method of examination and the findings in regard to albuminuria, inasmuch as albumin tends to disappear with age. There is a certain amount of evidence that poor mechanical use of the body tends to increase in later life and is the presumable cause of a certain amount of backache, etc., and the possible cause of various other disturbances. It is, therefore, incumbent upon us to attempt some means to improve this condition. By the use of this simple classification it has been possible to insist on the importance of recreative exercise in the students with poor mechanical use of the body, and to give them rather definite instructions and the necessary encouragement to improve their bodily mechanics. It is our experience that associated with this improvement is usually an improvement in general physical well-being. It has furthermore been of considerable interest to check up the association of general defects with this poor form of bodily mechanics. For example, we have found that with very few exceptions those individuals who have albuminuria persistently during the day, but who have none immediately after the recumbent period at night, are classified as group D in regard to posture. We have also found that those students who deviate from the average standards in pulse rate and blood pressure readings also tend to fall in this particular group.

In a similar manner, Dr. Stanley Cobb undertook a survey of the students from the point of view of what we finally designated as nervous stability. Dr. Cobb's paper in this issue of the JOURNAL presents the results of his study.

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In a similar manner, Dr. Stanley Cobb undertook a survey of the students from the point of view of what we finally designated as nervous stability. Dr. Cobb's paper in this issue of the JOURNAL presents the results of his study.

His study, while inconclusive, should, nevertheless, be stimulating to further work, because nervous instability bears a very definite relation to industrial inefficiency, just as it does to academic inefficiency in college life. If it were possible to classify men on the basis of nervous stability, it would be possible to make a much more intelligent selection of men for particular positions, and furthermore it would give the foundation for constructive advice toward the remedy of this condition in its early stages.

It is not always possible to separate exactly the physiological systems because, as is well known, these physiological systems are interdependent, and are all subject to nervous control. It is, indeed, probable that most of the symptoms referable to the cardiovascular system, when not of organic origin, are traceable to functional disturbances in the nervous system. The war gave us a considerable amount of data concerning a condition known as "effort syndrome"—a condition which we know now is very common in civil life. It apparently has no organic basis and is to be explained on the basis of functional disturbance of the central nervous system. In the University we are constantly brought face to face with this condition of effort syndrome, usually under the guise of so-called athletic heart. Consequently, the importance of the establishment of a proper standard in the examination of the heart is here peculiarly manifest. Numerous illustrations could be given in which a diagnosis of heart disease has been made, based on cardiac irregularity and the presence of murmurs and of certain symptoms related to the cardiovascular system, such as becoming easily winded on slight exertion. Such individuals may, in the course of time, appear again for examination for athletic competition and may or may not present the same objective findings, and very frequently present none of the subjective symptoms. The lapse of time usually has sufficed to suppress such a symptom as breathlessness on slight exertion. It is of considerable interest that the factors which seem to operate best in the interval of time which has lapsed are those factors which tend to stabilize the nervous system. While there can be no doubt that graded exercises are of great value, particularly in marked cases of effort syndrome, nevertheless very often an individual who was unable to undergo athletic competition one year may easily undergo athletic competition the following year, although he may have taken very little in the way of actual physical exercise.

I trust that I have made it clear that the physical examinations should be much more than a purely objective scrutiny of the bodily organs. The obvious and apparent organic defects will be relatively few in any industry. The value of the physical examination will depend upon the wider application of the examination to the actual functional capacity of the individual. In that particular field only very feeble beginnings have been made and the collection of data is for the future. While it is, of course, true that the situation in a university is different from the situation in an industry, nevertheless, there are many important features in common. There are two possible advantages on the side of health supervision in industry, namely, that the industrial workers are a step ahead of the university students in the progress toward their more or less fixed vocation in life, and that in industries one is dealing with actual conditions of life, whereas in the university one is dealing with the temporary and entirely preparatory conditions of life. Further-

more, in industry there are to be solved many special problems particularly related to the development of fatigue and the effect of fatigue upon the human system.

In industry, the constructive side of health supervision must be based upon carefully acquired data. The constructive efforts which result in better physical condition, better bodily functioning of the individuals concerned will inevitably result in an increased efficiency in the industry itself. But before there are adopted extensive programs for the systematic improvement of the physical conditions of the workers in industry, it is necessary that further progress should be made on the solution of some of the problems of physical examination itself.

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A REPORT ON THE BRIEF NEUROPSYCHIATRIC EXAMINATION OF 1,141 STUDENTS*

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IN 1914 physical examination of students was taken up at Harvard University. Dr. Roger I. Lee, Professor of Hygiene, has reported the method of examination and some of the results elsewhere (1) (2) (3). In 1916 an orthopedic examination of each man was also made under the supervision of Dr. Lloyd T. Brown and an interesting paper which bears important relation to this report has been published (4). Following this policy of taking up new fields of special examination as the need arises, Dr. Lee asked me, in the autumn of 1920, to plan a brief neuropsychiatric examination which might be added to the routine physical and orthopedic examinations. This seemed necessary to him because such a large number of the students showed symptoms of that vague but incapacitating malady known as "nervous instability."

METHOD OF EXAMINATION

In order to avoid the diffuseness likely to occur in examination for such an ill-defined entity, we decided to investigate four main questions:

1. What is the incidence of neurotic history in the group?
2. Can any physical sign be taken as an indication of nervous instability, or as indicating that the individual is potentially unstable?
3. Is endocrinopathy common, and what is its relationship to nervous instability?
4. After four years of observation do the men who showed certain symptoms at their first examination tend to fall into significant performance groups?

The last question, which is probably the most interesting, cannot be answered in this report. Here we can only hope to discuss the correlation between physical examination and past history.

The routine examination (see Figure 1) contains many neurological and psychiatric features, such as questioning concerning history of syphilis, habits, and sleep, and examination of pupils, thyroid, heart rate and rhythm, blood pressure variation with posture and knee jerks. It was decided, therefore, to add to the examination card a list of questions which might bring out any history of previous neurosis, and a group of physical observations (Figure 2) which would bear directly on abnormalities of the nervous system, especially the vegetative nervous system, which is known to be affected in neurotic and psychotic conditions.

The examination itself was carried out by a group of eight physicians who, besides being familiar with the routine examination, had discussed with Dr. Brown and me what was desired in each special question. Knee jerks, for example, had to be roughly standardized into absent, sluggish, active, and exaggerated, which terms were designated on the examining cards by the signs −, +,

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FIGURE 1

HARVARD UNIVERSITY

DEPARTMENT OF HYGIENE

Full name of student.....
Class.....Age.....Date of examination.....

FAMILY HISTORY

F., born in.....
M., born in.....

PAST HISTORY

Underline and give approximate age at which subject had any of the diseases listed in the square:

What injuries? .....
What operations? .....
Present general health .....Appetite.....Sleep.....hrs.
Have done.....; also.....
Am doing outside remunerative work.....hrs. per week
Usual recreation previously ..... " " "
" " now ..... " " "
Dates of successful vaccinations.....Failures.....
Typhoid vaccination .....
Cups tea average .....per..... Cigarettes average.....per.....
Cups coffee " ..... " ..... Pipes " ..... " .....
Swimming ..... Cigars " ..... " .....
Color-vision = ...

Measles
Pertussis
Mumps
Chicken-pox
Scarlet Fever
Typhoid Fever
Diphtheria
Malaria
Smallpox
Pneumonia
Pleurisy
Rheumatism
Tonsillitis
Influenza
Otitis Media
Gonorrhea
Syphilis
Constipation
Chorea
Convulsions

PHYSICAL EXAMINATION

Color.....Apparent Age.....Peculiarities.....
Eyes: Right.....Left.....Corrected to Right.....Left.....
Wears glasses, constantly, reading, distance, when obtained. Needs to see oculist.
Hearing: good, fair, poor. Needs aurist.....
Gen. Devl.: excel., av., poor. *N.:* thin, av., obese. *Skin:*.....
Skeletal Type .....
Distribution of fat and hair.....
Chest: cir. at xiphoid { Exp.....in. / Neu.....in. / Ins. .....in.
Scars .....
Acne: Face....., Chest....., Back.....
Weight:.....lbs. *Height:*..... *Pup.:* R. L. re. to l. and d. Size: Dance.
Teeth: good, av., poor, neglected, false.
Shoulders: norm., round. *Scapula:* norm., scaphoid. *Thyroid:* norm., sl. enlarged. *Vac.:* R. L. arm, leg, doubtful, irreg., good.
Chest: norm., flat, funnel, pigeon, flaring at base.
Heart: rate..... Regular, irreg., interm., A_2 P_2.
From med. line { Left nipple =.....cm. / L. bord. card. dul. (5th sp.) =.....cm. / R. bord. card. dul. (4th sp.) =.....cm. / Ap. imp. Seen, felt =.....cm.
Murmurs .....
Lungs .....
B. P. standing. S.....mm. D.....mm. recumbent. S.....mm. D.....mm.
Blood: Hgb. =.....% (Tallquist)
Abdomen: norm. Hernia: ing., fem., umb., epig. *Liv.:* edge.....felt. *Spleen:*.....felt.
R. Kid.:.....felt. *L. Kid.:*.....felt.
Penis: norm., circum. *Testes:* R.....L.....Abnormality: *Varicocele:* R.....L.....
Lymph N.: C..... Ax.....Epitr.....Ing.....
Knee J.: R.....L..... *Vert. Col.:* norm. Lordosis:..... Scoliosis:.....
dors.....lumb.....
Feet: { History ..... / Tender Points .....Shoes..... / Use .....
Long arches: R. high, low, flat. L. high, low, flat. Ant. Arches: R. present, absent. L. present, absent.
Nose: obstruction R. L. nostril.....Chr. Pharyn.....
Tonsils: 1, 2, 3, 4.....Removed totally, partially.....
Urine: Sp. G. = Alb. = Sug. = Sed. =

++, +++. Dermographia was tested for by sharply stroking the skin of the abdomen and chest with the pulp of the fore-finger, the appearance of a conspicuous red line being considered as "positive." Skeletal types or unusual developments were described best by adjectives such as slightly acromegalic, eunuchoid, feminine, etc., which, taken with a description of the distribution of the fat and hair, and notes on any unusual genital development, were intended to give an index of the endocrine balance of the subject.

FIGURE 2

Nervous symptoms
Convulsions
Chorea
Bed-wetting
Night terrors
Sleep-walking
Stammering
Development of size and weight and onset of puberty Shaving Voice
Any nervous symptoms at present
Adaptability Mood
Muscle tone
Tremor
Vasomotor, dermatographia, flushing, blushing, sweating, palpitation, sinus arrhythmia and blood pressure variation
Skeletal (type and development)
Distribution of fat and hair
Shape of external genitalia and their development

The questions for the determination of past history were somewhat standardized; thus, in asking about "mood and adaptability" the examiner would say: "Are you a good mixer? Lonely or sociable? How do you get along with people?" and "How are your spirits? Ever melancholy or especially elated?" The early development and onset of puberty was determined roughly by asking whether the student had ever had any period of being a "fat boy" or growing extraordinarily fast, and asking for the date of the first "wet dream" or emission, of the voice change, and the beginning of shaving. At first I examined many of the men myself, and worked with each examiner until it seemed that he understood what was desired. The latter part of the examining was carried on with less supervision.

RESULTS OF EXAMINATIONS

At the end of the examinations the results were tabulated in various ways and the tables analyzed for significant data as follows:

The incidence of neurotic history in the 1,141 men examined was 188—*i. e.*, 16.4 per cent. gave a history of one or more of these troubles:

	No.	Per Cent. of 188	Per Cent. of 1141
Abnormal mood or difficult adaptation	14	7	1
Nervous symptoms in past	2	1	0.17
Convulsions	5	3	0.43
Chorea	4	2	0.35
Bed-wetting	22	12	2
Night terrors	26	14	2
Sleep-walking	37	20	3
Stammering (34 still stammer)	44	23	4
Severe nervous breakdown	2	1	0.17
Nervous symptoms at present	78	41	7

Taking up the findings at the physical examination in relation to the histories obtained, we see that (Table 1) the men with neurotic histories differed physically from those with no such history only in more frequently showing exaggerated knee jerks and rapid heart beat and other vasomotor phenomena, such as dermographia, flushing, excessive sweating and palpitation, but these symptoms were found in the men with neurotic histories only 6 to 10 per cent. more frequently.

The presence of tremor, dilated pupils, acne, or variations in blood pressure with change of position did not seem to be significant in this connection—*i. e.*, these symptoms occurred just as frequently in the men with no history of nervous instability as in those with such a history. Only by following up these individuals with neurotic histories for years can we determine whether they are more *liable* to *future* breakdown than are the other men.

TABLE 1.—PHYSICAL FINDINGS IN RELATION TO HISTORY OBTAINED

Group	Tachycardia	Blood Pressure Variation	Other Vasomotor Phenomena	Dilated Pupils	Tremor	Exaggerated Knee Jerks	Acne	Neurotic History
	%	%	%	%	%	%	%	%
All the men examined (1,141)	25	14	19	10	7	10	26	16
No neurotic history (953) . .	23	14	18	9	7	9	27	0
Neurotic history (188)	33	14	25	11	7	16	25	100
Endocrinopathy (22)	18	9	36	22	4	9	4	13
Albuminuria (44)	33	11	25	11	4	14	34	23

Tachycardia indicates the men whose pulse rate was 100 or over during examination.

Blood Pressure Variation indicates that the difference between the systolic pressures standing and recumbent was more than 15 mm. Hg.

Other Vasomotor Phenomena indicates that there was excessive flushing, sweating, dermographia, attacks of palpitation or sinus arrhythmia.

Dilated Pupils indicates a diameter of 6 mm. or more.

Tremor indicates tremor of extended fingers.

Exaggerated Knee Jerks indicates that the knee flies out on a slight patellar tap.

Acne indicates conspicuous lesions on face or trunk.

Neurotic History indicates past history or present complaint of nervous disorder.

Since vasomotor disturbance seemed in some ways related to neurosis, other special symptoms of this category were analyzed — *e. g.*, of 285 men having tachycardia, 20 per cent. had systolic blood pressure variation of over 15 mm. Hg on changing position, and 9 per cent. had dermographia, whereas of the whole group only 14 per cent. showed unusual blood pressure variation, and 5 per cent. dermographia.

Again, of the 161 men having a blood pressure variation of over 15 mm. Hg as above mentioned, 9 per cent. also had dermographia. Of forty-four freshmen who showed albuminuria, 14 per cent. showed exaggerated knee jerks, 22 per cent. a neurotic history, 36 per cent. tachycardia, and 25 per cent. other vasomotor phenomena. Also, of twelve unclassified and Business School men who had albuminuria, 42 per cent. showed tachycardia.

In other words, it is more common to find tachycardia, sweating, flushing and exaggerated knee jerks among men who may be considered neurotic because of either their present complaints or their past histories, than among more stable individuals, but this increase only amounts to approximately 8 or 10 per cent.

Throughout the examinations a careful watch was kept for individuals who might be considered endocrinopathic, but out of the total group only twenty-two were discovered. They were classified as:

A. Precocious development (6)
B. Delayed development (8)
C. Abnormal development (8)

Of the men classed under "Abnormal development" only two showed conspicuous symptoms, and they were both of the *typus femininis*. There were two other less marked individuals of this type, and two others that suggested hypothyroidism. The remaining two ap-

proached the acromegalic type, but not one of the whole group of eight would have considered himself abnormal.

This number is too small to analyze further or to draw conclusions from, but it is interesting to note that as a group (Table 1) these men showed less neurotic history and acne, and more vasomotor disturbance and dilated pupils than the average. It is also of interest that sinus arrhythmia was not found at all in the delayed development class.

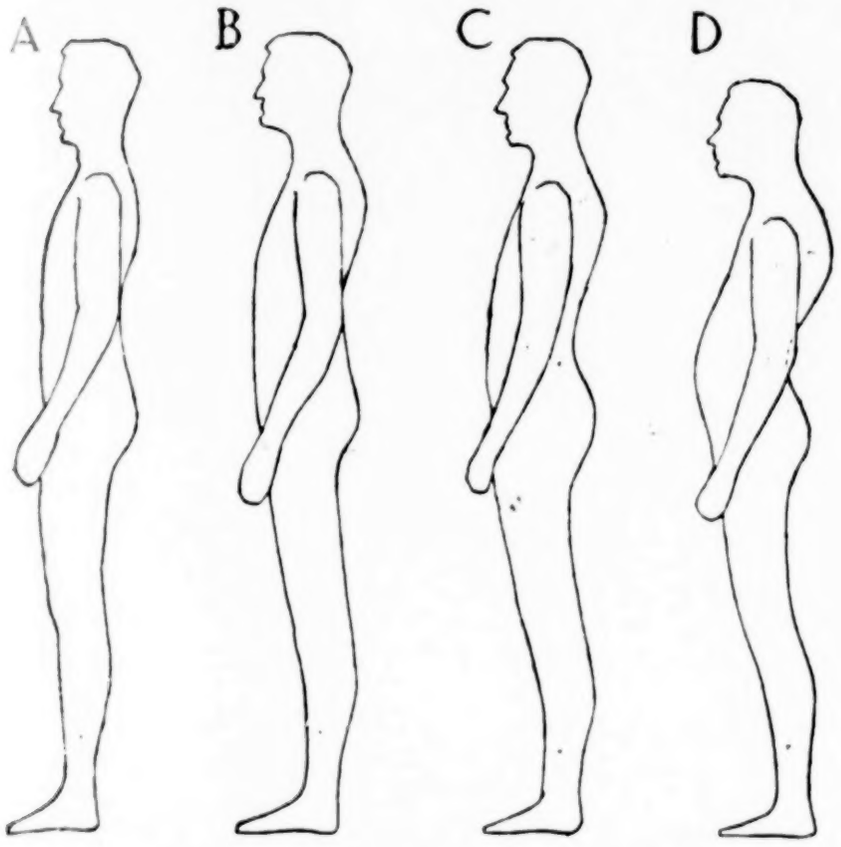

Fig. 3.—Diagram showing standard classes A, B, C, and D, according to bodily mechanics or posture.

Minor symptoms that might be considered due to "endocrine imbalance" were taken into consideration.

Perhaps the most interesting correlation obtained was from a tabulation of the nervous symptoms in relation to "bodily mechanics." Dr. Lloyd Brown (4) has described how the posture of each man is examined and classified, A men being normal, B men those who had only one or slight variation from the normal standard, C men those who had two, D men those who varied from the normal to the extreme in some or in all points (see Fig. 3).

Table 2 shows the 1,141 men divided into classes from A to D according to the excellence of their bodily mechanics, and a glance at the percentage of nervous symptoms indicates that men with good posture are distinctly less likely to have *tachycardia* and *variation* in blood pressure, although they just as frequently showed exaggerated knee jerks, sweating and flushing, and dermographia. There also seemed to be a relationship between *high blood pressure* and poor posture, for of 73 freshmen with systolic pressure over 140, 1 was in posture class A, 9 in B, 40 in C, and 23 in D. *Sinus arrhythmia* also was more

TABLE 2.—CORRELATION OF NERVOUS SYMPTOMS WITH POSTURE: PERCENTAGES OF A, B, C, AND D MEN

Group	Tachycardia	Blood Pressure Variation	Other Vasomotor Phenomena	Dilated Pupils	Tremor	Exaggerated Knee Jerks	Acne	Neurotic History	Increased Muscle Tone	Decreased Muscle Tone
	%	%	%	%	%	%	%	%	%	%
A men (21)	5	5	25	—	19	10	5	10	—	—
B men (178)	22	12	21	5	7	10	15	20	6	7
C men (597)	23	12	16	10	7.9	11	29	14	3	5
D men (345)	28.9	17	23	11	4	9	30	18	4	

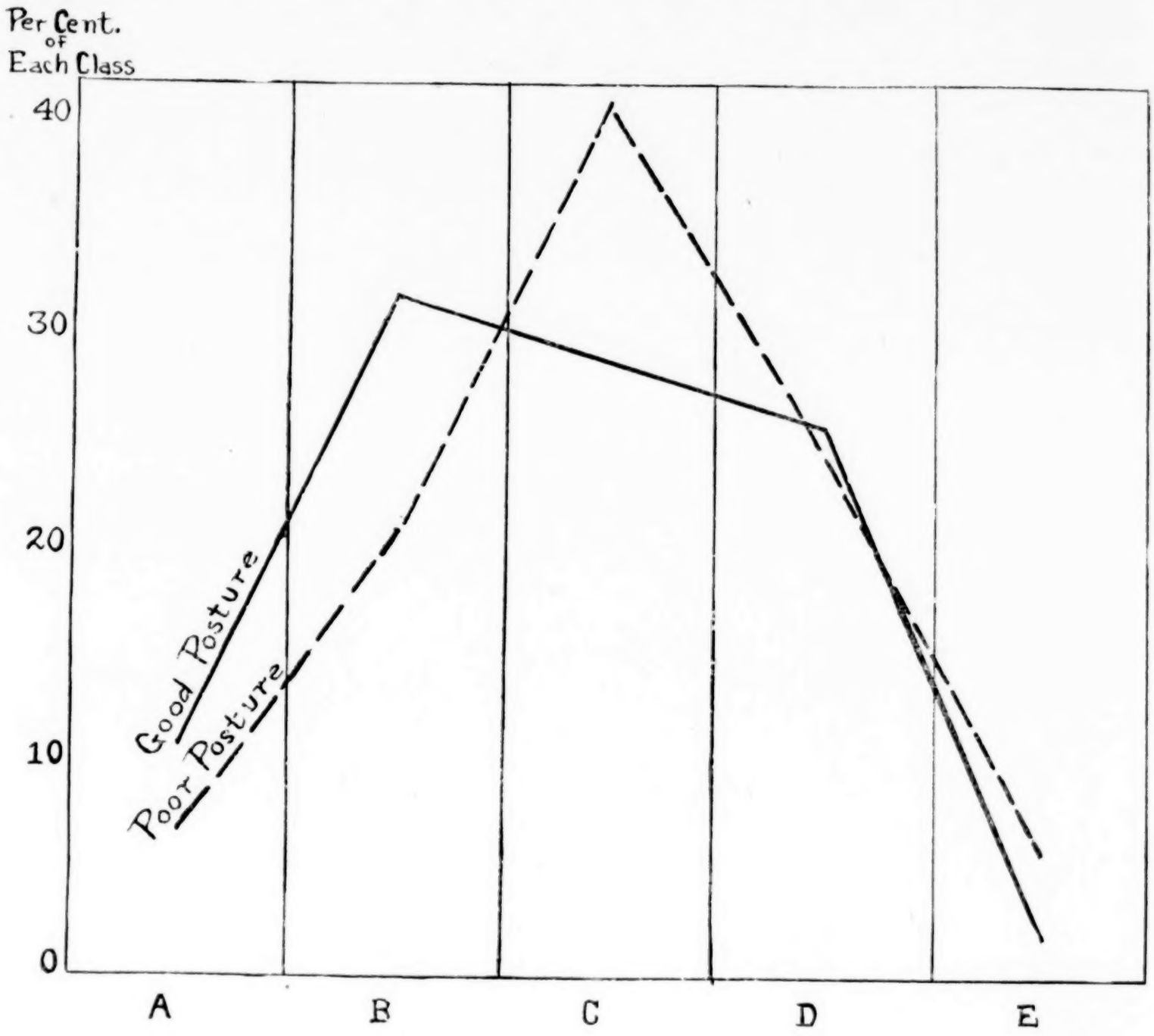

FIG. 4.—Group psychological test of 144 Business School men, made by Professor Starch.

Solid line indicates men of good posture from posture classes A and B. Broken line indicates men of poor posture from posture classes C and D.

A, B, C, D, and E are the grades obtained in the psychological test given by Professor Starch, A being the highest and E the lowest.

"Per Cent. of Each Class" indicates posture classes A and B grouped together, and posture classes C and D grouped together. The good posture men are considered as one class, and the poor posture men as another class. The percentage of each of these classes that obtained grades A, B, C, D, or E in the test was charted and a curve plotted.

commonly found among men with poor bodily mechanics; of 60 freshmen with sinus arrhythmia, none was in class A, 7 were in B, 27 in C, and 26 in D. Calculated in percentages, these relations are shown in Table 3, in which the percentage of men in each posture class is given, and also the percentage of each class which showed high blood pressure or sinus arrhythmia.

Finally, through the kindness of Professor Starch of the Graduate School of Business Administration, we were able to correlate the physical and mental examinations of a group of 144 Business School students. Only three men in posture class A took the psychological test, and they all attained low grades—one C, and two D. Of the 35 men with B posture who took the examination, 16 had honor grades (A and B), and only 1 failed in the mental tests. There were 74 men with C posture in the psychological tests, of whom 22 received A and B grades on the mental test, and 5 failed; while of the D men—32 in number—7 obtained honors and 1 failed. A rough graph of these figures indicates that men with good bodily mechanics stood a better chance of pass-

ing psychological examinations than did their less well set-up fellows (Fig. 4).

The general impression obtained from examining this large number of freshmen, and from talking to them informally, is that their problems have not yet defined themselves. If they had as yet had any emotional or intellectual problems that might be upsetting, they were inarticulate about them. In short, it seems too early for such examinations, and more valuable data could be obtained from a smaller group of men in a graduate school.

TABLE 3.—SINUS ARRHYTHMIA AND BLOOD PRESSURE VARIATION OF 585 FRESHMEN IN RELATION TO POSTURE

Posture Class	Percentage of 585	Percentage with Sinus Arrhythmia	Percentage with Blood Pressure Variation
A	2	0	7
B	16	8	10
C	52	9	13
D	30	15	13

Summary

History is the best guide to nervous instability—family history, past history and present complaints.

In a short fifteen-minute examination it is impossible to get a history with accuracy, and freshmen have few well-defined problems.

Vasomotor instability was found somewhat more frequently in the men with neurotic histories.

Tachycardia, blood pressure variation and dermographia were often found associated with each other and with exaggerated knee jerks. Men with albuminuria were likely to show all these symptoms.

Endocrinopathy was rare, but the small number of cases discovered showed more symptoms referable to the vegetative nervous system and less neurotic history and acne.

In men with bad mechanical use of the body, tachycardia, sinus arrhythmia, high blood pressure and variable systolic pressure were more common.

The men with good bodily mechanics passed better psychological examinations than did those with poor posture.

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STATIC EQUILIBRIUM AS A USEFUL TEST OF MOTOR CONTROL*

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UNSTEADINESS of motor control in gait and standing posture is a sign of disease or disordered function which, as a readily observable symptom, has served physicians of all times. Romberg was one of the first to recognize and emphasize its importance and to make specific tests. In his classical study of *tabes dorsalis* he recorded the inability of his patients to stand securely with feet together and with eyes closed. In 1851 he wrote, "It is now ten years since I have pointed out this pathognomonic sign, ... since then I have found it in a considerable number of patients, from far and near, who have applied for my advice; in no case have I found it wanting." Romberg's (1) unqualified statements greatly stimulated the study of motor functions in relation to disease. This specific test of his was most simple to apply, but since a normal person always sways somewhat, even though he endeavors to stand motionless, the physician had to rely on his personal clinical standards in judging this symptom.

Dr. Weir Mitchell was among the first to make this test of station numerically accurate and objective. It is incidentally stated in a paper by Mitchell and Lewis (2), 1886, that patients were tested for their relative power to stand steadily by placing them in front of a horizontal scale graduated in inches and located on a level with the ears. The observer, about 10 feet away, was seated in order to avoid his own swaying and observed with one eye, making separate readings for lateral and anterior-posterior positions. They found among healthy subjects standing with the eyes closed that the anterior-posterior movement is usually the larger, being about 1 inch, while the lateral swaying is about ½ inch, and they concluded that any large increase was suspicious. Hinsdale (3) (4), working in Dr. Mitchell's clinic about this time, took graphic tracings of station. One of his methods was that of "attaching to the top of the man's head a flat piece of cardboard, upon which was stretched some smoked paper.* The subject was then placed under an index, which was free to move up and down in a fixed line, and which traced curves on the paper as the subject who stood beneath swayed in any direction."† This ar-

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*The other method, the one which Hinsdale preferred, consisted in leading off from the head with two silk threads, one in the lateral axis and one in the anterior-posterior axis; these threads were carried around pulleys and made to move light levers writing on a kymograph. Thus, the two components of movement were registered and the extreme range of movement could be measured.

† The graphic registration of station as mentioned in later literature has usually been by this method, with the slight modification that sometimes the subject has had the writing point attached to the head while the smoked paper is suspended. The apparatus is referred to as the "ataxiagraph." The first illustration of it with which I am familiar is Dana, "Textbook of Nervous Diseases," New York, 1892, p. 38. Whipple, in his discussion of tests for steadiness of motor control (see "Manual of Mental and Physical Tests," Part 1, 1914, p. 156), gives the impression that the method and apparatus were originated by Crichton-Browne and used by him for detecting the presence of incipient or recent chorea. It is of minor importance but just as well to record that Sir James Crichton-Browne did not originate or use the ataxiagraph. To quote from a personal communication: "I cannot take credit for being the inventor of the ataxiagraph nor can I tell you who suggested it. I used to be content with the Romberg test and close observation, without instrumental aid." Such

rangement came to be called the "ataxiagraph." The dimensions of a rectangle which would just contain the tracing when applied to it parallel to the anterior-posterior and lateral axes were used as the numerical result.

By this same method Bullard and Brackett (5) a little later measured the "static equilibrium" of 181 "healthy men who were undergoing a competitive physical examination." Subsequently, Hancock (6) used it as a means to study the motor ability of children; Bolton (7) tried the ataxiagraph in his investigation of the relation of motor power to intelligence; and Wallin (8) used it in studying mentally defective children.

More recently this graphic measure of static equilibrium has found use among those interested in different phases of military science. Melville (9), in his contribution to military hygiene, found it useful in studying the "attention position," in properly arranging the load of the soldier's equipment pack, and in recording fatigue after marching. Gates (10) found that unusual steadiness of motor control in standing was one quality in the make-up of a good marksman. The physical examinations especially planned for aviation candidates have contained such static as well as dynamic tests, the belief being, as noted by Head (11), that through testing the prospective aviator's ability to balance himself on his feet, the examiner might exclude some candidates who would have difficulty in learning to fly and to make successful landings. These tests by examining boards were mostly made without any use of graphic registration or instrumental aid, and the protocol for such an examination of a prospective pilot in the United States (12) usually answered the question of static control with the word "firm." The young men who were examined for this branch of the service were practically free from gross organic disease and the Romberg test, in place of revealing lesions, served mostly to test the condition of physiological or psychological control in the men. There were certain workers, however, interested in the most efficient selection of aviators who believed that some graphic or quantitative record of static equilibrium was a reasonable test to apply to such candidates and might prove to some degree to be a measure of aptitude for flying. Stratton (13) and Henmon (14) have shown, after accumulating a considerable amount of data, that while excellent control of station is by no means a proof or, so to say, a pathognomonic sign of an aviator, such scores do correlate well with the later flying school records of the men tested.* The recent experience with the static equilibrium test carried out in an accurate and objective manner is therefore such as to recommend its more general consideration as one means of measuring neuromuscular control in selecting men for work, or in assessing their condition after work or when subjected to various influences.

Essential Features in the Measurement of Station

A graphic record of station theoretically provides three or more features which represent the swaying of the body

graphic registration for the involuntary movements during standing probably suggested itself independently to many observers. Leitenstorfer in "Das Militärische Training usw.", Stuttgart, 1897, credits it to Vierordt. I am indebted to Prof. F. H. Pike for the reference: H. Immermann, Deutsch. Arch. f. klin. Med., 1865-1866, *1*, p. 595, which also refers it to Vierordt: "Grundriss der Physiologie des Menschen, 1864, p. 408.

* Of the many psycho-physical tests applied to aviators by these authors, only one or two other tests give as high a positive correlation.

during the test period. These are: (*a*) extreme scatter or range of area covered; (*b*) actual length of the path traversed; and (*c*) number of movements or oscillatory rate of movement. The ideal score would be a combination and proper weighting of all of these. Practically, there appears no simple way to obtain the true length of path or oscillatory rate. The tracings on smoked paper, even though greatly magnified by projection, cannot be satisfactorily measured by a map tracer or similar method because of the utter confusion of the lines.* The authors just cited have contented themselves with measuring the extreme range of movement along the anterior-posterior axis and likewise along the lateral axis. To the use of this one feature as the expression of station there is the objection that subjectively the test is primarily that of standing motionless rather than of maintaining the vertex on a certain center. Within the area where there is no special strain or marked loss of equilibrium—and this area is relatively quite large—the subject tries each moment to avoid swaying rather than to return to the starting or central position. The fact is that the starting point rarely forms the center of the tracing and the subject has no accurate criterion for judging and locating the central position. The range is therefore a somewhat incidental feature of the record. Typical tracings show that most of the swaying movements occur within an area much smaller than the extreme range. These median or mean excursions should have their proportional part with the larger movements in forming the total score. Some mechanical means of automatically summing up all of the movements in terms of their anterior-posterior and lateral components thus appears desirable.

Description of Ataxiameter

The apparatus here described has been in use since 1919 and has proved both adequate and practical as a means of recording static equilibrium in this quantitative way. For convenience it is called an ataxiameter in order to distinguish it from the ataxiagraph. While the ataxiameter provides a graphic record if desired, and in certain respects this is still useful, the unique feature of the apparatus is the possibility at the end of a test of reading off directly a score in millimeters for the accumulated or total amount of sway in each axis, forward, backward, left, and right. The three diagrams, A, B, and C, which comprise Figure 1, will make clear the simplicity of the device.

A square wooden frame D, 61 cm. in outside dimensions and adjustable vertically on the rigid pipe E (Diagram B), is secured at any desired height by two clamps, with winged nuts F, F. A movement adder, such as is shown in side elevation in B, and in end elevation in C, is mounted under each corner of the wooden frame. From the collar Q, which connects with the subject's helmet, later mentioned, four fine silk threads pass, one to each of the four movement adders. At the end of each silk thread there is a weight of 5 gm. (See R in Diagram B.) Each

* Graphic tracings made by Hinsdale's "thread method" of recording lend themselves fairly well to the measurement of path length. Hinsdale seems never to have given attention to this feature since he confines his discussion to the extreme range and rate of movement. The general subject of tremor has usually been viewed in this way. See Dana, "The Clinical Characters and Diagnostic Significance of Tremor," *Med. News*, Phila., 1892, *61*, 673; and Eshner, "A Graphic Study of Tremor," *Jour. Exper. Med.*, 1897, *2*, 301, which refer to a considerable amount of literature on the topic.

thread passes over an aluminum pulley S, in Diagram C, which is 180 mm. in circumference at the bottom of the groove. The groove is wide and very smooth so that no fiber of silk will catch.

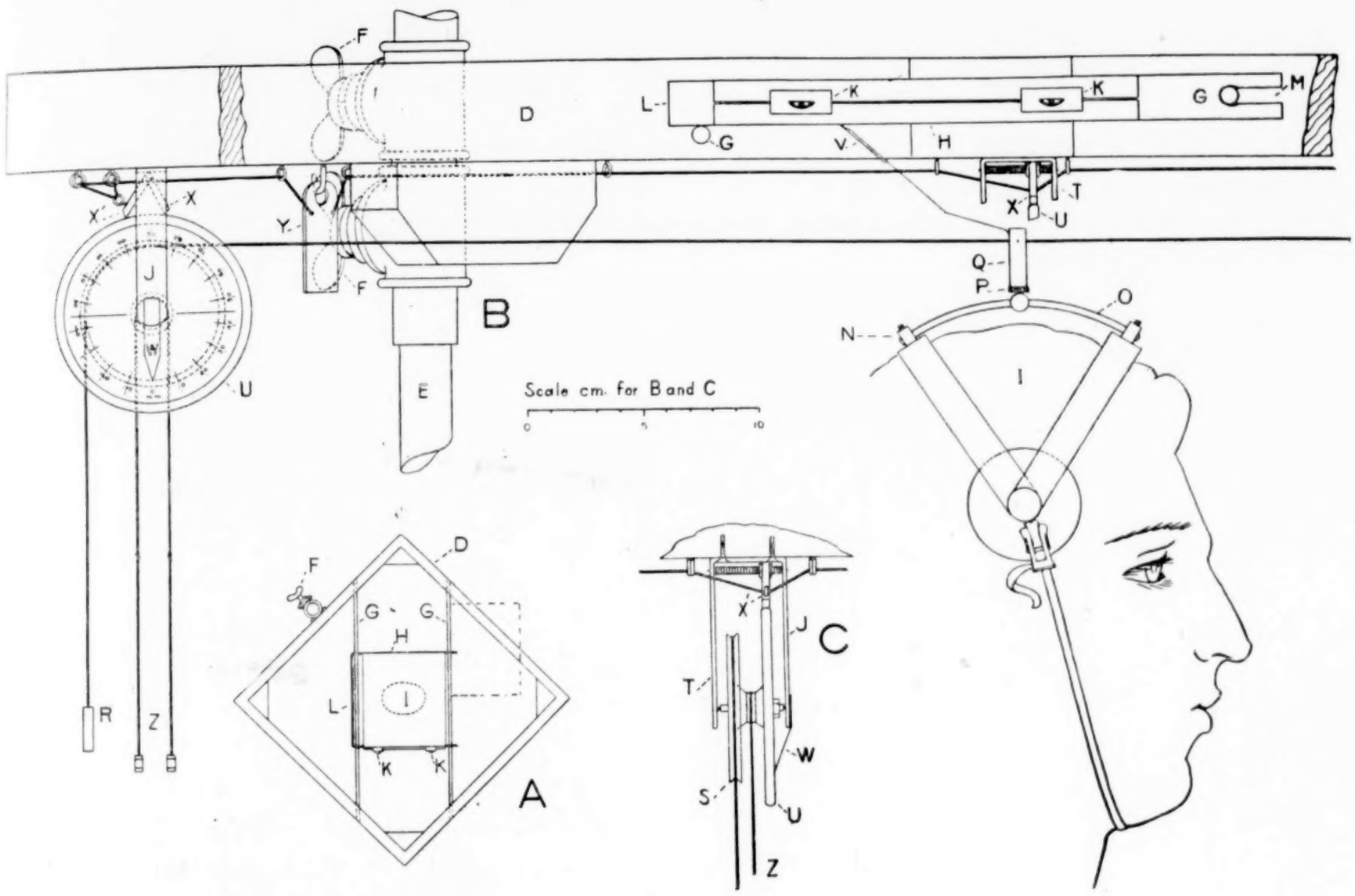

FIG. 1.—Diagram of the ataxiameter, an apparatus for measuring the swaying of the body when a man tries to stand motionless.

The small cone bearings are under very slight tension by the frame JT, which is made of brass strip. Secured to the same shaft with the pulley S is a larger thin aluminum pulley U. This pulley is 85 mm. in diameter and the periphery is knurled. Around the periphery is stretched a rubber band (3-inch by ½-inch bands have been found satisfactory). Two small pawls, X and X′, are arranged above U, so that they may engage freely with the rubber band stretched about its periphery. Pawl X is always in contact with the pulley unless lifted by the operator at the time of zeroizing. With both pawls in contact, as in the figure, the wheel will not turn in either direction. During the preliminary adjustment of a subject to the apparatus all the movement adders thus remain zeroized until the moment of actually starting the test. This is done by unhooking the weight Y, and dropping it synchronously with starting a stop-watch. This weight, by drawing on a cord, lifts all four locking pawls and thus permits each adder to turn freely in one direction. The adder in Diagram B, for instance, would obviously accumulate all the anterior movements. Whenever the body sways backward, X holds firmly and the silk thread drawn by its 5-gram weight slips easily in the groove of the pulley, taking up all slack and making ready instantly to register any further movement in the forward direction. Movements as small as 0.5 mm. will be positively recorded.

When the test period has elapsed, the

weight is suddenly lifted to its hook and instantly all four adders are locked. The subject is released and the scales read. The graduations on a scale represent millimeters, and the reading is in reference to the index W. To indicate whether the scale U of a movement adder has been turned through one or more revolutions during any test period, a cord Z, with a small weight at each end, is passed over the shaft. The cord is graduated and the final separations of the weights show how many, or if any, revolutions (180 mm.) are to be added to the scale reading.

While, as just stated, all movements even though very slight, cause a positive turning of the adders, it must be remembered that the final total reading is not the exact length of the path of swaying but is the sum of all anterior-posterior and lateral components of these movements. The four threads attached to the subject's head represent four axes along which it is particularly arranged to have movements occur. If the swaying were from and through the center and only along these axes, the score and length of path would closely agree, indeed would be identical if the four adders were *infinite* distances from each other. Since actually opposed adders are 73 cm. apart in this case so that the apparatus will not be inconveniently large, a direct forward sway, for example, of 20 mm. from the center will produce a reading of 20 mm. on the adder back of the head and also a turn of 0.5 mm. in each lateral adder, the sum of 21 mm. having thus a positive error of 5 per cent. A similar movement of 50 mm. would show a plus error of 14 per cent., but it is seldom that a subject wanders so far from center. He does, however, sway in other axes than those which are directly front, back, left, and right, and roughly traces all sorts of plane geometrical figures.* It is evident that diagonal movements will produce a score for anterior-posterior and lateral components which may be 40 per cent. or more in excess of the actual path length. This difficulty cannot be removed by wide separation of the adders so long as they are arranged in the form of a square. It is therefore necessary to assume that in any one of a group of two-minute station tests the movements in all axes are about equally likely to occur, and only on this basis are the sums for the measured components comparable when dealing with a series of tests on the same individual or on a group of subjects.

The helmet N, in Diagram B, is made of two springs which terminate in leather-covered, padded disks, 5 cm. in diameter. It is not uncomfortable and is easily adjusted without entangling the subject's hair. On the rod O, connecting the two springs of the helmet, a stud P is arranged to be moved and secured as required so as to be central in the frame D, and vertical, ready to receive the collar Q. To this collar is attached a delicate spring with writing pen V, as well as the silk cords which actuate the movement adders. The smoked paper record sheet H is supported on two rods G, G, mounted in the wooden frame, and may be freely moved along the oral axis of the subject's head. Since the greater excursions of body swaying are forward and backward movements, this lateral adjustment of the paper permits several

* If all the movements could be assumed to be linear, then the length of path could be closely approximated as follows: Add together the forward and backward readings (thus treating opposed movement adders as constituting one meter) and square their sum, do the same for the two lateral readings, add the squares and take the square root of their sum. Since most swaying movements appear to be more curved than linear in character, it seems better to use the ataxiameter readings without any mathematical treatment.

records to be taken on the same sheet. The paper, by means of two clips K, K, is secured to frame L. This frame, bent up from iron strip, 3 mm. thick by 18 mm. wide, is open at one end with the prongs notched (see M in Diagram B) so that the record for protection may be tilted up against the wooden frame during periods of adjustment. The two prongs thus serve as springs and keep the kymograph paper taut while freely suspended. It is of prime importance to avoid friction and noise in recording the body sway for, as is well known, if the subject can avail himself of these secondary criteria he is almost certain to do so. The apparatus here described meets these requirements and without much attention remains in workable adjustment.*

Factors Influencing Station

A number of factors influence the stability with which the erect posture may be maintained. Of these the following will be touched upon rather briefly: anatomy and physiology of the "attention position;" location of the feet and influence of footwear; height and weight; sex and age; respiration and heart-beat as possible producers of swaying; and the psychic factor. Melville has well stated some of the anatomical considerations. The human body is symmetrically disposed on either side of the sagittal plane, but asymmetrical as regards the coronal plane, which largely accounts for its possessing greater lateral than anterior-posterior stability. It is composed from above downwards of several segments (head, trunk, thigh, leg, and foot) which are not rigidly fixed to each other. Each segment possesses a center of gravity peculiar to itself which must be considered in relation to the point of support on the segment just below and to the area of support on the ground. "The maximum of stability and the minimum of constraint would be obtained if the various centers of gravity and the various points of bearing were all in the same vertical line, and if that line fell immediately in the center of the area of support" (9). Cleghorn (15) quotes the Weber brothers as stating that this condition is fulfilled and that erect posture requires no muscular effort for maintenance. The facts seem contrary to this. The head is so supported that it tends to fall forward, while the head and trunk together have a center somewhat behind the main support at the hip joint with the resulting tendency to fall backward. For the thigh the center is behind the coronal plane, but a little in front of the point of bearing at the knee joint with the tendency to fall forward; hence in the normal comfortable erect posture the quadriceps extensor is relaxed and the patella freely movable. Thus far the divergencies from the coronal hip-plane are 1 cm. or less, and the muscular activity necessary is little more than normal tonus. The point of bearing at the ankle joint is 5 cm. behind the coronal plane, consequently here is the location of greatest tension and it is chiefly the soleus muscles which keep the body from falling forward. Bullard and Brackett (5) found that in 80 per cent. of all their tests the position of the head at the end of the trial was definitely in front of the starting position. In the use of the ataxiameter it is found that the adder for anterior movements nearly always has the largest reading. The soleus muscles appear to relax gradually during the test, allowing the total center of gravity to shift forward toward the ball of the foot, with the result that the

* The apparatus may be obtained from Mr. Warren E. Collins, 584 Huntington Ave., Boston, Mass.

strain is much increased and fatigue rapidly develops, particularly if the subject continues his effort to stand motionless. Subjects who are to be tested should not be required to stand for a long while unsupported awaiting their turns.

and with the eyes closed. This has, of course, been done, as is revealed by Table 1 which is a summary of certain of the earlier data. Hinsdale, in 1887, with twelve normal adults found closure of the eyes to increase the sway in the two general directions an average of 54

TABLE 1.—SUMMARY OF EARLY DATA FOR STATION TEST

Author	Subject Material	No.	Feet	Eyes	Time	Movement	
						Ant.-Post.	Lat.
					min.	*mm.*	*mm.*
Mitchell and Lewis (1886)	Normal adults	?	together	closed	..[1]	25[2]	13[2]
Hinsdale (1887)	Normal adults, young	12	together	open	..[1]	25	20
	Normal adults, young	12	together	closed	..[1]	46	25
	Normal adult, young	1	shod	open	..[1]	39	6
	Normal adult, young	1	bare	open	..[1]	73	45
	Girls, from 7 to 13 yrs.	25	together	open	..[1]	28	27
	Boys	11	together	open	..[1]	32	29
	Blind inmates	39	together	—	..[1]	43	36
	Deaf-mutes, 14 to 24 yrs.	17	together	open	..[1]	22	24
	Deaf-mutes, 14 to 24 yrs.	17	together	closed	..[1]	33	30
	Adults, locomotor ataxia	6	together	closed	..[1]	75–175	75–150
	Adults, cases of chorea	10	together	open	..[1]	60	37
Bullard and Brackett (1888)	Normal men, 20 to 30 yrs.	150	V-form	open	½	38	20
	Normal men, 20 to 30 yrs.	150	V-form	closed	½	35	20
Hinsdale (1890)	Normal adults	12	together	open	..[1]	24	9
	Normal adults	12	together	closed	..[1]	29	19
Hancock (1894)	Normal children, boys 5 yrs.	35	together	open	1	58	52
	Normal children, boys 5 yrs.	35	together	closed	1	67	58
	Normal children, girls 5 yrs.	22	together	open	1	58	50
	Normal children, girls 5 yrs.	22	together	closed	1	55	51
	Normal children, boys 6 yrs.	47	together	open	1	51	43
	Normal children, boys 6 yrs.	47	together	closed	1	57	52
	Normal children, girls 6 yrs.	18	together	open	1	57	37
	Normal children, girls 6 yrs.	18	together	closed	1	56	43
	Normal children, boys 7 yrs.	23	together	open	1	50	42
	Normal children, boys 7 yrs.	23	together	closed	1	60	54
	Normal children, girls 7 yrs.	13	together	open	1	39	33
	Normal children, girls 7 yrs.	13	together	closed	1	48	38
Miles (1917)[3]	Aviation candidates	62	V-form	open	1	38	21
	Aviation candidates	62	V-form	closed	1	37	18

[1] The length of test is not stated; it was probably 1 minute.
[2] The extreme range of movement is represented by the values in these columns.
[3] Data unpublished. Results taken into account in the work of Stratton (13) and Henmon (14). The subjects were in excellent physical condition.

Of the three or more types of sensory impressions usually involved in the maintenance of equilibrium (16), the influence of the visual factor is the most accessible to direct determination. Tests may be made with the eyes open

per cent. In twenty-five girls, ages 7 to 13 years, he states that the increase was about 40 per cent. From thirty-nine blind people he secured average scores which, on the basis of results for normal adults with eyes open, show an in-

crease of about 76 per cent., the performance of the blind thus being a little poorer than that of normal subjects with eyes closed. Seventeen deaf-mutes showed an average increase of 37 per cent., and he reports some increase in cases of chorea tested. Again, in 1890, Hinsdale found that a group of twelve normal adults showed increased swaying with eyes closed, amounting to an average of 65 per cent. In these tests the subjects first stood with eyes opened and then continued the test with eyes closed; whether or not they had previously made a short practice trial is not recorded.

Hancock, 1894, measured 158 children, ages 5 to 7; of these 110 were less steady with eyes closed. He tested with eyes open for one minute, allowed a rest of thirty seconds, and then recorded with eyes closed for one minute, and for his whole group an average increase was found of 13 per cent. Contrary to the foregoing results, Bullard and Brackett with their large group of young men in the competitive examination found slightly better (4 per cent.) stability with the eyes closed. Miles, 1917, testing aviation candidates also found an improvement of 9 per cent. when the eyes were closed. In the test of the aviators the men without preliminary practice stood at first with eyes open for one minute, then simultaneously with the command to close eyes the frame* carrying the smoked paper was given a quick lateral movement so as to separate the two tracings, and the man continued one minute with lids closed. The men had not been tested for station previously. The first minute was, to quite an extent, a period of adjustment, by the end of which they had begun to feel easier and were therefore in a position which they could more comfortably maintain. The unitiated, on beginning the station test, are apt to lean a little backward and gradually come forward, finishing in front of the center. As the second minute was really the latter half of the aviator's test, it would therefore be expected to show less anterior-posterior range. In spite of this difficulty and the elements of nervousness and practice, which must have been important also in the tests of Bullard and Brackett, 45 per cent. of the aviators were less steady without the use of vision.

The magnitude of the visual factor can best be shown by a group of measures on a subject who has had much practice in taking the test with closed eyes and has thus come to feel that he need not rely on vision. A fragment of such data given without discarding any trials is presented in Table 2. This subject had performed several hundred station tests always with closed eyes but no tests had been made for three months prior to those reported in the table. These tests were two minutes in length and successive, with a rest (sitting) of two minutes after each. The position of the helmet on the head was not changed during the series. The feet were in V-position—*i. e.*, heels together, inside lines of feet 45°. The data are given separately for each direction. The three tests with eyes open show a total average of 273 mm., with a variation of 2 per cent., while the average score for the usual test, that is, with eyes closed, is 508 mm., with a range of about 10 per cent. Aided by visual impressions of his movements in relation to the objects in the room, this practiced subject could more quickly stop or compensate the swayings and was thus able to improve his steadiness suddenly by approximately 45 per cent. Data for the two condi-

*This was an earlier apparatus and not the ataxiameter described in the present article.

tions show some minor characteristic differences other than in the amount of anterior-posterior and lateral sway. In both cases, the backward sway is less than the forward. With eyes shut it was 89 per cent. of the forward, with them open only 73 per cent. Vision does not correct the relative tendency to sway forward but increases it, probably because the fixation of an object in the room conduces to movement in that direction. Left and right sway are about equal in both cases, respectively, and the lateral sway is 60 per cent. of the anterior-posterior with eyes closed, while it is 64 per cent. with eyes open.* With vision playing a part, any lateral deviation tends to be instantly corrected rather than that the subject should hold motionless in the new position. It is futile to question the importance of vision as an aid to maintaining station, and the test for general use in measuring normal individuals will therefore be less complicated if made with eyes closed.

We shall not be able, figuratively, to close the eyes of the "kineticstatic sense" (17). These impressions from the labyrinth are bound to function along with the great mass of kinesthetic sensations. Their relative prominence and importance in the test are of interest that we may have a clearer idea of what is being measured in station. In the first place, it is instructive to notice the experience of the young aviator* who is practically helpless if he has to fly in the dark or in a cloud and cannot use his vision by which to correct the position of his plane with the horizon. More than one aviator in recounting his experience has said: "Came out of the cloud to find the earth unexpectedly rushing up towards me." The wind pressure, vibration, and cold, and being strapped into a snugly fitting seat, cause the kinesthetic sensations of the aviator to be confused and blurred. Ideally the laby-

TABLE 2.—INFLUENCE OF VISION ON STATION AS MEASURED BY THE ATAXIAMETER ON A PRACTISED SUBJECT

Axes of Movement	1 Eyes Open	2 Eyes Shut	3 Eyes Open	4 Eyes Shut	5 Eyes Open	6 Eyes Shut	Av. Eyes Open	Av. Eyes Shut	Per Cent. Increase Eyes Shut
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	
Front . . .	100	185	95	174	94	145	96	163	75
Left . . .	47	92	60	100	53	81	53	91	72
Back . . .	60	158	76	138	75	154	70	150	114
Right . . .	73	98	44	99	46	101	54	99	83
Total . .	280	533	275	511	268	481	273	508	86

* The graphic tracings for eyes closed have average anterior-posterior and lateral ranges of 31 and 21 mm., while for eyes open, 39 and 9 mm. The tracings in the latter case appear to be made up of smaller movements as if the neck muscles were playing an important rôle.

* In recent years the work of von Stein, Ewald, Högyes, and Bárány has become familiar and through the impetus of certain problems arising from practices in military aviation has been supplemented by an enormous amount of data on the reactions following stimulation of the semicircular canals. These form the kinetic labyrinth, a receptor mechanism which seems well adapted for the detection and analysis of rotary motions. The static labyrinth, as distinct from the kinetic, through the pressure of the otoliths on the maculae of the saccule and utricle, is supposed to provide sensory cues as to the position or tilt of the head and to be acted upon when linear body movement is accelerated or retarded.

rinth should be able to take care of just such conditions but practically any impressions from it are not sufficiently strong to be a sure basis for orientation. Similarly in *tabes dorsalis* kinesthetic sensations are reduced or arrested. The tabetic can stand with some stability while he can see, but in the dark or with eyes closed the impressions from the labyrinth are too vague or weak to suffice.

Since the paper by James (18), it has been recognized that deaf-mutes are not subject to dizziness on being whirled around. They do not show the characteristic reactions following rotation, douching, or electrical stimulation of the canals. It is therefore reasonable to suppose in many cases that the labyrinth or the eighth nerve is destroyed. Yet these individuals commonly show satisfactory equilibration.† Hinsdale found that seventeen deaf-mutes (see Table 1) were all able to stand well with eyes closed, the averages of 33 and 30 mm. for anterior-posterior and lateral sway comparing favorably with results obtained with normal subjects.

The recent experiments of Griffith (19) are noteworthy in this connection. He concludes that the processes which constitute the experience of dizziness or vertigo are "(1) kinaesthesis from the eyes and neck and in the arms, (2) pressure from the region of the abdominal viscera, the chest and head, and (3) certain vascular processes which supply an obscure background and which give to the whole experience a characteristic shading." If ordinarily every tilt and turn, acceleration and retardation of movement, gave a clear-cut sensory impression from the labyrinth, these would constitute a prominent portion of our everyday sensory experience. We know this is not the case, but surely in vertigo, if at any time, this sensory quality ought to be sufficiently apparent to be recognized, at least. Griffith was unable, however, to discover any process which could be called "sensation of rotation" or "sensation of movement."

It is not surprising, then, that in maintaining erect posture with eyes closed, one is conscious of only kinesthetic and tactual impressions. The labyrinth must be assumed to be functioning during station probably by increasing the muscular tonus. It is doubtful if the slight changes in tilt during standing are sufficient stimuli to cause it to initiate different compensatory movements. If the average height of adults be taken as about 5 feet, 8 inches or 173 cm., then a sway at the vertex of 30 mm. is equal to just 1° of body tilt from the vertical axis. A continuous movement of this amount is unusual. Thus, there is provided a rather slight opportunity to stimulate a receptor mechanism which never supplies better than vague, weak impressions, even the existence of which are in doubt as sensory data. We are therefore warranted in considering station as primarily a test of muscular equilibrium against gravity. The swaying is perceived and controlled in so far as this takes places through the lower limbs almost entirely. The body's total center of gravity being a little above the horizontal line joining the heads of the femora and requiring to be kept somewhere near central to the area of support, the main task is evidently for the legs. There is but little movement at the neck and hips, as shown by testing subjects in the sitting posture, and it is not difficult to keep these muscles in

† They sometimes experience difficulty in the dark or when under water, but normals are not entirely free from such disturbances. Being in rough water in the dark is somewhat like flying in the dark.

equilibrium, having once gotten them into a comfortable relationship. The ankle is the point from which swaying takes place and, as is known from the work of Goldscheider (20), it is the least sensitive of the large joints to angular rotation, its threshold being from 0.75° to 1.50°. The soleus muscles are the ones most vigorously contracted to withstand the displacement of the center ahead of the support at the ankle. They are bound to vary in their contraction separately and between themselves. Here, then, is where the subject most actively exerts control to maintain a fine balance between these muscles and all that may act as antagonistics. This, in the final analysis, is the nature of the test.

Sensations arising from changes of pressure on different parts of the soles of the feet and of strain within the feet are of great use in controlling equilibrium. Severe anesthesia of the soles has long been known to produce swaying almost as marked as the typical Romberg symptom itself. Anything which interferes with the usualness of these sensations of pressure and strain will be reflected in decreased steadiness. Since it is customary for adults to wear shoes, station is more secure with the feet shod than with them bare. Hinsdale (Table 1) made such a test with one subject, and found a very great increase in the total range of sway on removal of shoes. The anterior-posterior sway was increased 87 per cent. while the lateral sway was multiplied more than seven times. Typical results with the ataxiameter may be reported for this factor. A normal young man of muscular type, wholly unpractised in the test, made ten trials with a total average of 895 mm. Then the shoes were removed for four trials which averaged 974 mm. The shoes were replaced and five trials made, the average being 813 mm. The average without shoes is 14 per cent. increase over the average figure with shoes. A practised male adult gave an average of 537 mm. for five trials with shoes, and an average of 667 mm. for five trials without shoes, an increase of 24 per cent. It is the habituation to shoes which aids us in standing motionless when they are worn.

After practice, swaying in most cases would probably be less with bare feet since the uncramped foot in contact with a flat floor would be better situated for sensing any shift in the center of gravity. Results obtained with an artist's model used to posing with bare feet illustrate this point. Two preliminary trials were made with the model wearing medium weight low-heeled, low-cut, walking shoes, her usual footwear; these trials gave scores of 559 and 515 mm. With the shoes removed, trials three and four gave scores of 398 and 392 mm., an average improvement of 26 per cent. The shoes were replaced and a fifth trial made, with a result of 594 mm. At another time with *cold* bare feet five trials, well separated with rest periods, gave an average of 474 mm. With the model, the station test may be considered well practised, owing to her occupation. Such facts indicate the importance of sensations from the feet, the necessity of using the same shoes throughout a series of tests on a subject, and the desirability of approximately controlling temperature.

Aside from training, a factor which aided the model in standing unshod was the fact that the feet thus covered a slightly larger area. The smaller the base of support the more difficult it becomes to keep the center of gravity comfortably centered. The Romberg test is made with the feet together, causing the sway to be exaggerated. Under these

conditions there are moments of distinct loss of balance, resulting in sudden large jerks of the body. Series of tests with the ataxiameter show more consistency between successive trials if the area of support is sufficiently large so that these great jerks very seldom occur. A group of tests, two or more of each kind, on a trained subject taken under comparable conditions, with shoes, show results which illustrate the influence of area of support on stability of station. It is seen (Table 3) that when the feet are

TABLE 3.—STABILITY OF STATION AS MODIFIED BY AREA OF SUPPORT

Position of Feet	Total Score
	mm.
1. Heels and toes together, Romberg position	1,039
2. Parallel, separated by 20 cm.	421
3. Heels together, feet angle 45°, V-position	587
4. Heels 20 cm. apart, toes 10 cm. apart	500
5. Heels 20 cm. apart, toes 30 cm. apart	421
6. Parallel, separated by 40 cm.	529
7. Left heel 25 cm. ahead of right on same line, toeing out	1,213
8. Left heel 25 cm. ahead and 20 cm. laterally of right	791

close together or far apart the swaying is much increased. The greatest stability is found when the heels are about 20 cm. apart and the feet parallel or toeing outward. The V-position, used as the standard in tests reported in this paper, is nearer that of maximum stability than it is to the typical Romberg position. This makes for more consistent co-operation from all classes of subjects, as they do not feel themselves placed at a disadvantage in the test.

As the swaying is principally from the ankle, it is to be expected that the taller and heavier subjects will show greater unsteadiness at the vertex. The testing of a large number of individuals classified as to height and weight would be necessary to procure a correction factor for reducing the measures on several subjects to a strictly comparable basis. A hint of the influence of height and weight on recorded stability may be obtained from the following set of trials. A man 180 cm. tall, weighing 75 kg., made several trials of the station test with an average score of 499 mm. He then put on a long overcoat with weights well distributed in the pockets and elsewhere upon it, the total addition to his weight being 25 kg. The average for several tests made with the added weight was 606 mm.—*i. e.*, about 20 per cent. more swaying for an increase of one-third of the body weight. Other tests were made extending the height by the use of a rod placed up the back so that the connection with the ataxiameter would be 198 cm. from the floor in place of 180 cm. With this artificial increase of 10 per cent. in height, the average score became 657 mm., which is approximately 30 per cent. more swaying than normal. From these trials the factor of height appears to exert more influence than weight in the ratio of about 4 to 1.

Since children are shorter than adults, they should show less swaying were other conditions the same.* Hancock (Table 1) finds that both boys and girls, ages 5 to 7, sway absolutely more than adults. With eyes open there is an increase in control with each year. The girls are in general steadier than the boys. Hinsdale measured girls and boys, 7 to 13 years, and found about the same range of sway as with the adults. The girls swayed less than the boys by about 10 per cent. The ataxiameter thus far has not been used especially to gather

* Fernald, in his article on The Defective Delinquent Class Differentiating Tests, *Am. Jour. Insan.*, 1912, *68*, 537, has devised a standing test which he calls "Achievement Capacity Test." The subject stands on one foot and rests the other with as even a pressure as possible on a lever system which he keeps balanced as long as possible. Fernald states that the age factor is largely eliminated since the strength and development of the leg muscles most closely correspond with body weight.

data on sex or age differences, but the following data which are at hand are interesting:

	Average Score *mm*	Variation %
8 Girl Scouts, age 16 years..	848	16
11 Adult women	731	14
16 Adult men	745	24

The men covered a wider range in height and on the average were somewhat taller than the women, which is to their disadvantage in directly compared scores. On the contrary, having longer, broader feet, and so a larger base, they have this advantage of the women. The two factors tend to counterbalance and in these data the average results for adults of both sexes agree closely.

In attempting to stand motionless for just a few seconds it is natural to suspend respiration. Probably inspiration and expiration slightly shift the center of gravity along the anterior-posterior line. Graphic records (3) (4) made by using threads, connected with the subject's head, a method similar to the ataxiameter connection but which produces up and down tracings on kymograph paper, show the swaying, particularly the anterior-posterior, to be made up of a series of waves. These waves have a little resemblance to quite irregular respiration curves. Hinsdale concluded that the waves of swaying do not correspond wholly or fractionally with respiration rate. From the inspection of a number of such tracings made with the ataxiameter it is certainly clear that there are places in nearly every record where a direct correspondence seems evident. But the same records show that the swaying waves continue at approximately the same size and rate during intervals of fifteen to thirty seconds while respiration is suspended. While it is proved that these movements do not depend upon the acts of respiration, it is still possible that these waves may result from slight reflex contractions or alternating changes of muscle tonus associated with respiration. On the other hand, any process of balancing commonly results in something of a pendular movement. From these tests of Hinsdale and from the tests with the ataxiameter it is apparent that subjects should be advised to breathe normally during the station test.*

Such factors as apprehension, distraction, and suggestion have been noted by those who have employed the station test as being important influences on stability. Especially if the subject is blindfolded or has his eyes closed, it surely is obvious that the experimenter should not be walking about him or talking with him, nor should other individuals be allowed to move about in the same room watching or commenting on the test or on other topics. It is convenient to control attention and mental attitude somewhat by having the subject count silently with a clock ticking seconds. Since he knows the test is going to continue, for example, 120 seconds, he is able to apprehend its progress and will not begin shortly to feel that the experimenter has forgotten him. If a test like that of station has to be denominated a "general motor test," this is no warrant for giving it in a loose and general way, but should stimulate effort to achieve careful control. The discussion in the preceding paragraphs of some of the influencing factors is to emphasize that useful data, even in such a simple test as station, cannot be obtained without care.

* No waves for heart-beat could be identified in the tracings. "Aviation Medicine in the A. E. F." Washington, D. C., 1920, p. 123, specifies that the breath should not be held during steadiness tests.

Improvement of Station with Training

Hancock reports that "in 30 cases (children) the tracings were repeated at a later date, without material difference in size and fully as miscellaneous movement." Without referring specifically to station, Henmon, working with aviators, records that "practice effects are slight for daily tests over a period of fifteen days." A series of measurements were made in 1920 at the Nutrition Laboratory in order to determine the influence of training on the test. Twelve adults, nine women and three men, all of whom were regularly working at the Laboratory, were tested on the ataxiameter once each day between the hours of 8 and 10 A. M. for a period of twenty-one successive days, excepting Sundays and holidays.* The complete data cannot be reproduced here. The average for the first day was 694 mm., slightly better than the averages reported on page 328 of this paper. The twenty-one days may be divided into three blocks of seven days each. The following general averages are thus obtained: 643, 560 and 528 mm. They show progressive improvement in stability, the second group of days being 13 per cent. better than the first, and the third 5.5 per cent. lower than the second. The graphic tracings taken in connection with the ataxiameter readings were carefully measured to find out if there was a similar change in the gross range of sway. The three groups of seven days each gave total averages for all subjects:

Anterior-posterior range (mm.)	48.3	46.1	42.7
Lateral range (mm.) ...	20.0	18.3	18.9
Rectangular area (sq. mm.)	966	844	807

There was a decrease in the range of forward and backward movement while the lateral range did not change much during the last fourteen days. The rectangular area within which the swaying occurred decreased at first by 12.6 per cent. and then by 4.4 per cent. These improvements with training are substantially the same as those indicated by comparison of the ataxiameter readings, but these latter vary from each other, treating the seven-day groups separately, by an average of only 3.5 per cent., while the gross range of sway shows a variation of 6.5 per cent.—*i. e.*, nearly twice as much.

Eight of the subjects tested at the Nutrition Laboratory continued the tests for thirty-six days from the start, and after an interval of six weeks, including four weeks' vacation, were again tested for twelve days. It will be convenient to arrange these results in six-day groups or what may be termed weekly averages. This has been followed in Table 4 where the daily averages are all presented arranged by weeks during which the test was continued. The first value at the top of column 1, 640 mm., is the total average ataxiameter score for the eight subjects on the first day. The first result in column 2, 524 mm., is the average score for the seventh day and so on. The weekly averages provide the following series of scores: 574, 506, 486, 482, 489, 506, vacation, 530, and 490 mm. The variations of a weekly score from the daily scores of that week range from 2.5 to 5.1 per cent. with no regular or progressive change. The weekly scores indicate consistent improvement up to and including the second week in July—the fourth week of the tests—with a total decrease

* These tests were painstakingly made by Mr. E. S. Mills. His assistance and the co-operation of those who served as subjects are gratefully acknowledged. As usual, the tests were two-minute tests, with eyes closed and feet in V-position, in a quiet room, the subject counting silently during the period.

in swaying of 11.8 per cent. There was a slight loss in steadiness during the fifth week and a definite loss in the sixth when the factor of training was more than offset by the tedium of the test, and the physical laxness preceding vacation. After four weeks of vacation and two weeks of work at the Laboratory, this

TABLE 4.—INFLUENCE OF PRACTICE ON STABILITY OF ERECT POSTURE

Days of Week	Weeks during Which Tests Were Continued								
	June 17–30		July 1–31					Sept. 13–25	
	1	2	3	4	5	6		7	8
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*		*mm.*	*mm.*
1	640	524	473	489	465	496	*Vacation 6 Weeks*	560	525
2	588	527	449	456	488	532		559	527
3	560	545	510	490	534	518		518	487
4	543	491	498	483	492	504		511	481
5	543	484	504	471	478	495		520	464
6	570	467	484	503	476	492		514	457
Av. . . .	574	506	486	482	489	506		530	490

latter interval being judged sufficient time for getting back into routine, the tests were resumed. The score for the seventh week, 530 mm., is just about half way between that for the first and second weeks, showing a retained improvement from training of 7.6 per cent. after a lapse of six weeks. On the eighth week the score approached quite nearly to the previous minimum. While station as a motor test is found from these data to follow the law of improvement with practice, as is the case with all known voluntary neuromuscular performances, it improves rather less than the average of such tests (21) (22) (23). This is a feature which recommends its use in those circumstances where it is impossible to preface the testing by giving the subjects a long period of preliminary practice.

Summary

The ataxiameter as a means of carefully measuring station in man has been used at the Nutrition Laboratory for investigating the influence on neuromuscular control of such conditions as those before and after the taking of food, physical weakness associated with diabetes, prolonged exposure to cold, fatigue resulting from muscular work, and the ingestion of dilute alcoholic beverages. Data could be given from such experiments to illustrate the sensitiveness of the station test and the type of results which may be expected from its use. But such fragmentary data tend to mislead the reader as to their bearing on the problems with which they deal and can best be withheld for publication in their proper connection. It has been the object of this article to call the attention of those interested in mental and physical tests to the static equilibrium or station

test as one well deserving consideration for general use.

1. A general review is presented, indicating some uses previously made of the station test.

2. A relatively simple apparatus called, for convenience, an ataxiameter, is described. This automatically accumulates all the anterior-posterior and lateral components of the movements directly in millimeters of sway, and provides a convenient method for making the test.

3. The anatomical and physiological considerations which influence stability of station and the quantitative influence of several of these factors have been shown by original data. This constitutes a description of how the test should be made.

4. Results for a long series of measurements are presented and demonstrate that, although subject to practice, station is not very markedly improved by training.

5. The test is put forward as a convenient and sensitive measure for variations in the efficiency of the neuromuscular mechanism of man.

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CENSUS OF SAFETY AND HEALTH WORKERS

All industrial physicians and surgeons, industrial nurses, and other persons engaged in industrial health work are to be included in the census of safety and health workers now being taken by the National Safety Council in all parts of the country. Although health work in industry, along with safety, has made great strides in the past few years, it is not at present known how many persons are engaged in either of these activities, who they are, or where they are located. This is the first time an attempt has ever been made to list all the industrial safety and health workers. Public safety workers will also be included in the census.

It is believed that the results of the census will give a good indication of how extensive the safety and health activities now being carried on are. The census will include not only members and employees of members of the National Safety Council, but all persons engaged in industrial safety and health work whether connected with the Council in any way or not. The Council has almost as deep an interest in industrial health work as in accident prevention, and is very closely allied with the American Association of Industrial Physicians and Surgeons. Many health workers and companies employing health workers are numbered among the Council's membership.

Industry in general and the nation at large will profit from the results of this census. It will enable the Council to find quickly speakers on industrial and public safety for any occasion in any locality; authors for special articles on accident prevention; writers of safety text-books; lecturers on accident prevention and industrial health work for universities and colleges. The Council at present continually receives requests from industrial companies, municipalities, civic associations, clubs, schools, colleges, and other organizations for help in finding speakers or writers on safety subjects. The census records will greatly increase the facilities of the Council for filling such requests.

Every reader of this publication who is professionally engaged in industrial or public accident prevention or industrial health work — whether he is devoting all or only part of his time to accident prevention — is urged to assist in the taking of this census by sending to the National Safety Council, 168 North Michigan Avenue, Chicago, his name and the other data requested in the Council's census form, which follows:

Name .....

Company or organization .....

City ..... State .....

Nature of company's business .....

Is safety your principal work? .....

Please check other activities you engage in:

Fire protection	Engineering (other than safety)
Health and sanitation	Legal
Workmen's compensation and claims	Insurance
General executive (such as manager or superintendent)	Welfare Educational
	Industrial relations

How long have you been in your present position? .....

Technical or other special education? .....

Signed .....

Title .....